Long-term VHE γ-ray monitoring of bright blazars with a dedicated Cherenkov telescope

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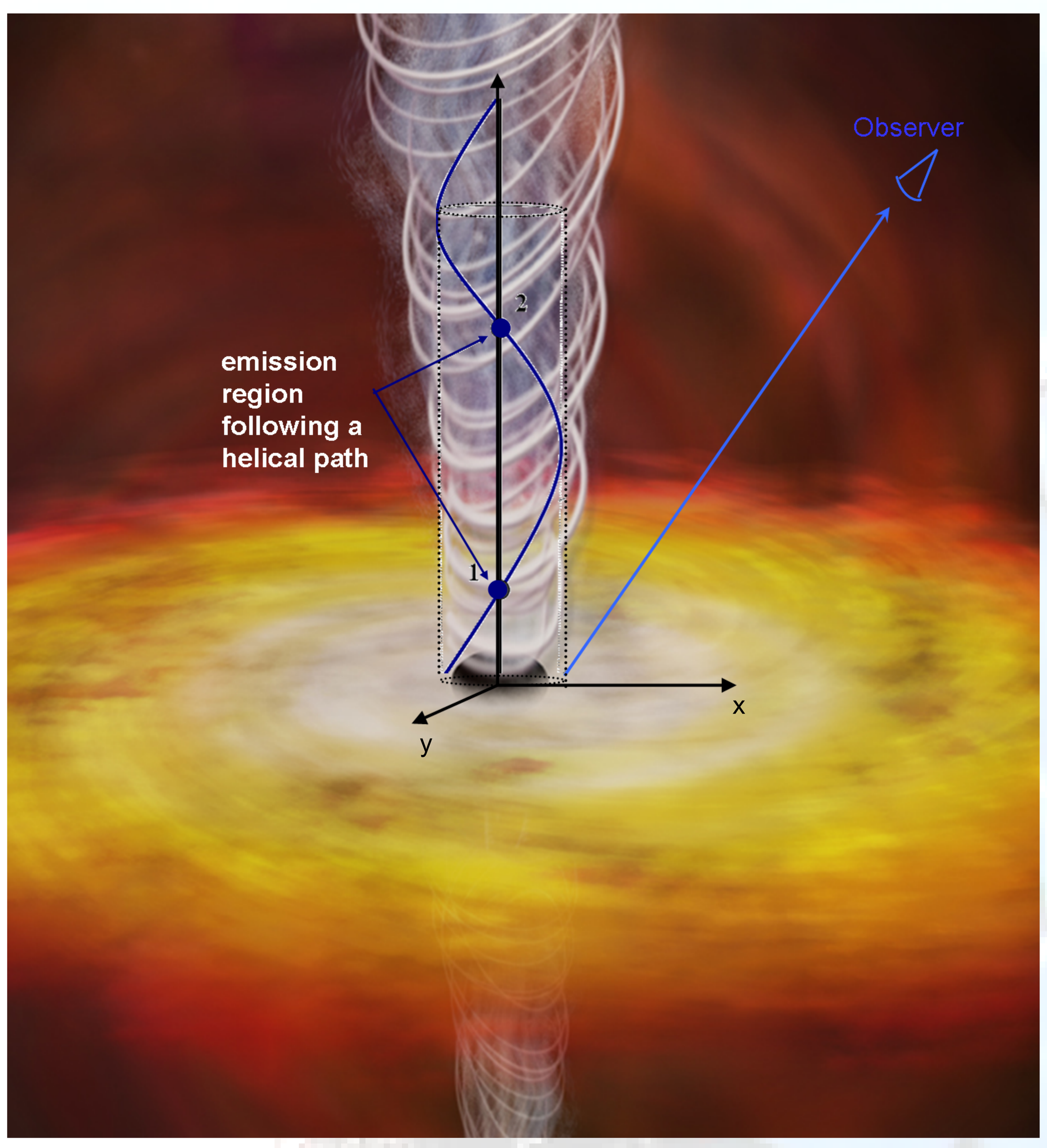
We intend to set up a robotic imaging air Cherenkov telescope with low cost, but high performance design for remote operation. The goal is to dedicate this gamma-ray telescope to long-term monitoring observations of nearby, bright blazars at very high energies. We will (i) search for orbital modulation of the blazar emission due to supermassive black hole binaries, (ii) study the statistics of flares and their physical origin, and (iii) correlate the data with corresponding data from the neutrino observatory IceCube to search for evidence of hadronic emission processes. The observations will also be able trigger follow-up observations of flares with higher sensitivity telescopes such as MAGIC, VERITAS, and H.E.S.S. Common observations with the Whipple monitoring telescope are planed to start a future 24h-monitoring of selected sources. The telescope design is based on a full technological upgrade of one of the former telescopes of the HEGRA collaboration still located at the Observatorio Roque de los Muchachos on the Canarian Island La Palma (Spain). After this upgrade, the telescope will be operated robotic, its sensitivity will greatly be improved and a much lower energy threshold below 350 GeV will be achieved.

Introduction Since the termination of the HEGRA observations, the succeeding experiments MAGIC and H.E.S.S. have impressively extended the physical scope of gamma ray observations by detecting tens of formerly unknown gamma ray sources and analyzing their energy spectra and temporal behavior [1]. This became possible by lowering the energy threshold from 700 GeV to less than 100 GeV and increasing at the same time the sensitivity by a factor of five.

To fully exploit the discovery potential of the improved sensitivity, the discovery of new, faint objects has become the major task for the new telescopes. A diversity of astro-physical source types such as pulsar wind nebulae, supernova remnants, microquasars, pulsars, radio galaxies, clusters of galaxies, gamma ray bursts, and blazars can be studied with these telescopes and limits their availability for monitoring purposes of well-known bright sources.

But there are strong reasons to make an effort for the continuous monitoring of the few exceptionally bright blazars. This can be achieved by operating a dedicated monitoring telescope of the HEGRA-type, referred to in the following as DWARF (Dedicated multiWavelength Agn Research Facility).



Artistic view of an Active Galactic Nucleus.

On top a scetch of a helical jet path caused by orbital modulation in a binary black hole system – a possible explanation for long-term variability of blazars. [3]

Science case The variability of blazars, seen across the entire electromagnetic spectrum, arises from the dynamics of relativistic jets and the particle acceleration. The jets are launched in the vicinity of accreting supermassive black holes. Theoretical models predict variability arising from the interplay between jet expansion, particle injection, acceleration and cooling [2].

To overcome the limitations of biased sampling, for variability investigations a complete monitoring database for a few representative bright sources needs to be built up.

An understanding of this variability will deepen our knowledge about

- the composition and generation of the jets, intimately connected to the physics of the ergosphere of rapidly spinning black holes embedded into the hot plasma from the accretion flow.
- the plasma physics responsible for highly efficient particle acceleration, bearing similarities to plasma physics of the interaction between extremely intense laser beams and matter.
- the orbital modulation of jets due to binary black holes expected from galaxy merger models.

Assuming conservatively the performance of a single HEGRA-type telescope, long-term monitoring of at least the following blazars is possible: Mrk421, Mrk501, 1ES2344+514, 1ES1959+650, H1426+428, PKS2155-304. We emphasize that DWARF will run as a facility dedicated to these targets only, providing a maximum observation time for the program. At least one of the proposed targets will be visible any time of the year. For calibration purposes, some time will be scheduled for observations of the Crab nebula, which is the brightest known VHE emitter with constant flux.

In detail the following investigations are planned:

- As a direct result of the measurements, the duty cycle, the baseline emission, and the power spectrum of flux variations will be determined and compared with variability properties in other wavelength ranges.
- The lightcurves will be interpreted using models for the nonthermal emission from relativistically expanding plasma jets.
- The black hole mass and accretion rate will be determined from the emission models. Estimates of the black hole mass from emission models, a possible orbital modulation, and the Magorrian relation (relating the black hole mass with the stellar bulge mass of the host galaxy) [4] will be compared.
- When flaring states will be discovered during the monitor program, MAGIC will issue a Target of Opportunity observation to obtain better time resolution.
- Correlating the arrival times of neutrinos detected by the neutrino telescope IceCube with simultaneous measurements of DWARF will allow to test the hypothesis that flares in blazar jets are connected to hadronic emission processes and thus to neutrino emission from these sources [5,6].

  The investigation proposed here is complete for both neutrino and gamma observations, and can therefore lead to conclusive results.
- The diffuse flux of escaping UHE cosmic rays obtained from AUGER or flux limits of neutrinos from IceCube, respectively, will be used to constrain models of UHE cosmic ray origin and large-scale magnetic fields.
- Multi-frequency observations together with the Metsähovi Radio Observatory and the optical Tuorla Observatory are planned. The measurements will be correlated with INTEGRAL and GLAST results, when available. X-ray monitoring using the SWIFT and Suzaku facilities will be proposed.
- The most ambitious scientific goal of this proposal is the search for signatures of binary black hole systems from orbital modulation of VHE gamma ray emission [7]. In case of a confirmation of the present hints in the temporal behaviour of Mrk501, gravitational wave templates could be computed with high accuracy to establish their discovery with LISA.

Furthermore, operating a smaller but robotic telescope is an essential contribution to the next plans in ground-based gamma-ray astronomy. It is necessary to obtain know-how for the operation of future networks of robotic Cherenkov telescopes, e.g. a monitoring array around the globe or a single-place array like CTA.

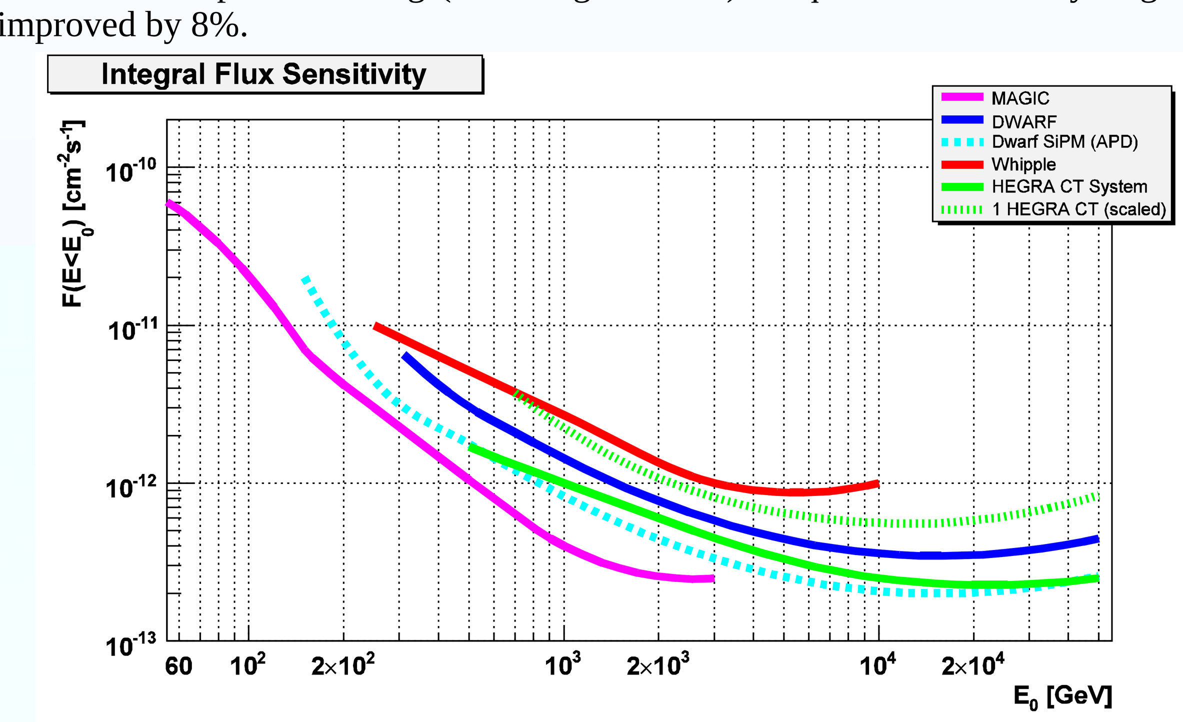
Picture of the HEGRA CT3 when it was still operational and a scematic view of the camera plane.

Photomontage of DWARF as it will look like and a schematic view of the camera plane.

Technical setup At the Observatorio del Roque de los Muchachos (ORM), at the MAGIC site, the mount of the former HEGRA telescope CT3 now owned by the MAGIC collaboration is still operational. Basic support from the shift crew of MAGIC is guaranteed, although robotic operation is the primary goal. Robotic operation is necessary to reduce costs and man power demands. Furthermore, we seek to obtain know-how for the operation of future networks of Cherenkov telescopes. From the experience with the construction and operation of MAGIC or HEGRA, respectively, the proposing groups consider the planned focused approach (small number of experienced scientists) as optimal for achieving the project goals. The available automatic analysis package developed for MAGIC is modular and flexible, and can thus be used with minor changes for the DWARF project [8].

Camera For long-term observations stability of the camera is a major criterion. To keep the systematic errors small, synchronous background determination from the night-sky observed in the same field-of-view is mandatory (so called wobble-mode). Having a camera large enough allowing more than one independent position for background estimation increases sensitivity further by better background statistics. This is the case if the source can be shifted 0.6°-0.7° out of the camera center. To decrease the dependence of the background measurement on the camera geometry, a camera layout as symmetric as possible will be chosen. Consequently a camera allowing for wobble-mode observations should be round and have a diameter of 4.5°-5.0° to completely contain shower images of events in the TeV energy range. To achieve this requirements a 313 pixel camera can be build based on the experience with HEGRA and MAGIC. Photomultipliers with a diameter of 19mm and with a quantum efficiency improved by 20% with respect to the old CT3 system are considered. They ensure a granularity which is enough to guarantee good results even below the flux peak energy.

If development of Geigermode-APDs (QE >50%) will be fast enough, respectively the price low enough, and their long term stability is proven well in time, their usage will be considered. For a transition time one of the old HEGRA cameras might be used. With a special coating (wavelength shifter) its quantum efficiency might be improved by 8%.



Integral flux sensitivity of current and former Cherenkov telescopes as well as the expectations for a dedicated long term monitoring telescope (DWARF), both with a PMT- and a APD-camera [9,10,11,12]

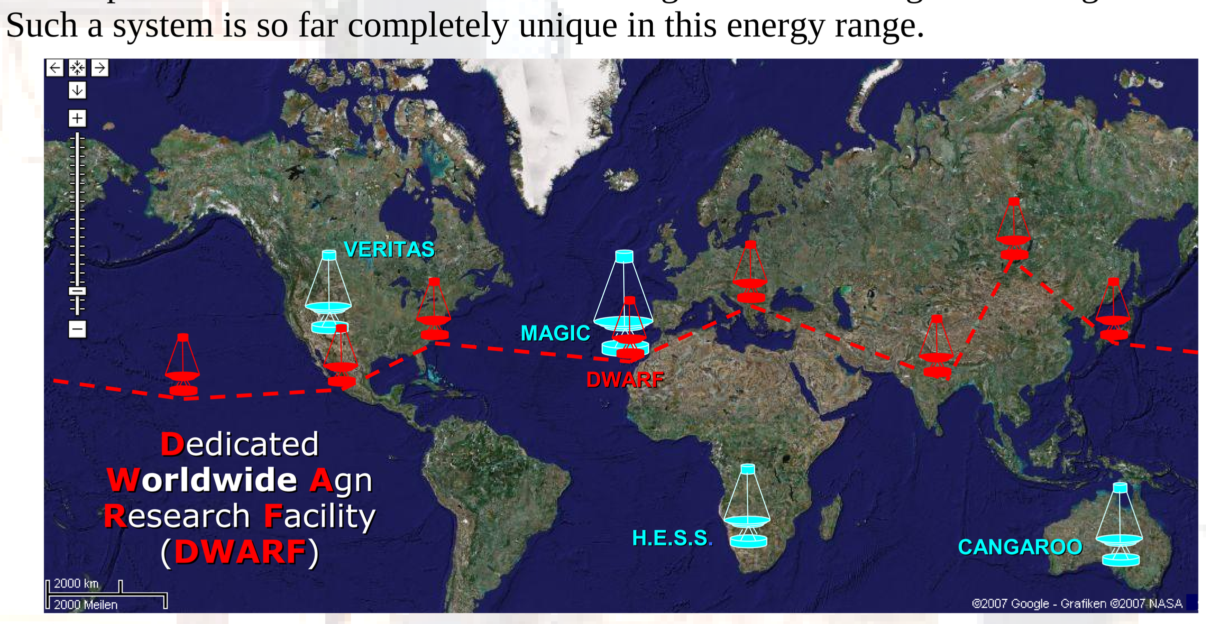
Camera support By over-coating the protection window in the front of the camera with an anti-reflex layer of magnesium-fluoride a gain in transmission of 5% is expected. Each PM will be equipped with a light-guide. The current design will be improved by using a high reflectivity mirror-foil, to reach a reflectivity in the order of 98%. In total this will gain another 15% in lightcollection efficiency compared to the old CT3 system.

Data acquisition For the data acquisition system a low-cost hardware readout based on an analog ring buffer (Domino II/III), currently developed for the MAGIC II readout, will be used. The low power consumption will allow to include the digitization near the signal source which makes an analog signal transfer obsolete. The advantage is less pickup noise and less signal dispersion. By high sampling rates (0.5GHz-1.2GHz), additional information about the pulse shape can be obtained. This increases the over-all sensitivity further, because the short integration time allows for almost perfect suppression of noise due to night-sky background photons. Assuming conservatively storage of raw-data at a readout rate of 30Hz the storage space needed is less than 250 GB/month or 3 TB/year.

Mirrors The existing mirrors are replaced by new plastic mirrors. The cheap and light-weight material has formerly been used for Winston cones flown in balloon experiments. The mirrors are copied from a master, coated with a reflecting and a protective material. By a change of the mirror geometry the mirror area can be increased from 8.5m² to 13m². This includes an increase of ~10% per mirror by using a hexagonal layout. To keep track of the alignment, reflectivity and optical quality of the individual mirrors, and the point-spread function of the total mirror, during long-term observations the application of an automatic mirror adjustment system, as successfully operated on the MAGIC telescope, is intended.

Conclusion The setup of a small telescope dedicated for long-term AGN monitoring is easily feasible. Such an activity is motivated by a variety of physical questions to be answered by the integration of this instrument in multiwavelength observations.

Future extensions The known duty cycle of 10% (~1000h/year) for a Cherenkov telescope operated at La Palma limits the time-coverage of the observations. Therefore we propose a worldwide network of (<10) small scale Cherenkov telescopes to be build in the future allowing 24h monitoring of the bright AGNs. Such a system is so far completely unique in this energy range.



Possible distribution of Cherenkov telescopes in a future worldwide network for AGN monitoring.

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